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Stamate, Eugen

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Charge separation in a magnetized three-dimensional plasma-sheath-lens

E. Stamate

Plasma Physics and Technology Programme, Risø DTU, Technical University of Denmark
Frederiksborgvej 399, Roskilde 4000, Denmark

Charge separation in a magnetized 3D plasma-sheath-lens is demonstrated by simulations and experiments. The presence of the magnetic field makes the charge kinetics within the potential structure of the sheath mass selective. This fact combined with previously demonstrated discrete and modal focusing effects provides a possibility to detect mass peaks from 1 up to a few hundreds units atomic mass using a magnetized plasma-sheath-lenses of a few cm in diameter. Experiments are performed in a device operated at pressures below 10 mTorr with three ECR plasma cells in gas mixtures of $Ar/SF_6/O_2$. An axial magnetic field adjustable from 0 up to 600 Gauss is created by two coils. Mass spectra are visualized measuring the etching profile resulted by the incidence of different ions species on the electrode creating the plasma-sheath-lens.

1. Introduction

Various applications relies on plasma processing for etching, deposition, implantation, passivation, ashing and other technological steps necessary for fabricating silicon wafer based electronic devices or general treatment of surfaces. Several factors including injected power, gas composition, pressure, external biases and electron heating mechanism can be used to control the plasma parameters. However, the continuous reduction in size for the desired patterns requires even more precise tuning including a new generation of sensors that need to be process transparent, easy in maintenance, sensitive to chamber conditions, accurate and reliable and that can provide direct information on more parameters than specified above. Of particular interest is to know the ion species and the radicals that can contribute to the processes tacking place at the surface for performing the desired modification. Conventional mass spectrometry and emission or absorption spectroscopy are state-of-the-art for such diagnostics but their wide applicability is limited due to high costs.

This work introduces a new principle for a mass sensor based on a magnetized plasma-sheath-lens.

2. Principle of operation

Plasma-sheath-lens is a three-dimensional potential distribution of customized shape, formed by the space charge surrounding a biased electrode-insulator interface placed in plasma. The discrete and modal focusing effects [1,2] have been revealed recently for this type of electrostatic structures formed in plasma and several applications including sheath thickness evaluation [3], negative ion detection [4] and extraction of positive or negative ion beams have been developed [5]. A non-magnetized plasma-sheath-lens acts as a kinetic energy separator, but it is not mass sensitive. The modal and discrete focusing effects are schematically explained in Fig. 1. The conductor-insulator interface (conducting electrode at the top) forms a sheath edge profile with a strong curvature that affects significantly the trajectories of ions entering the sheath from its lateral side. For example, the ion following the dashed trajectory 1 will change its velocity with almost 180° in a flight of less than 8 mm (modal focusing) while ions entering the sheath between locations 3 and 4 will all be focused to a narrow region on the electrode surface (discrete focusing). The impact locations on the electrode surface for ions entering the sheath edge delineated by the *xy* plane (or radial coordinate *r*) and z<0 are shown in Fig. 2 where from one can easily identify the formation of a spot-like structure at the centre by modal focusing and the passive surface (no ion impact) near the edge of the electrode by discrete focusing.

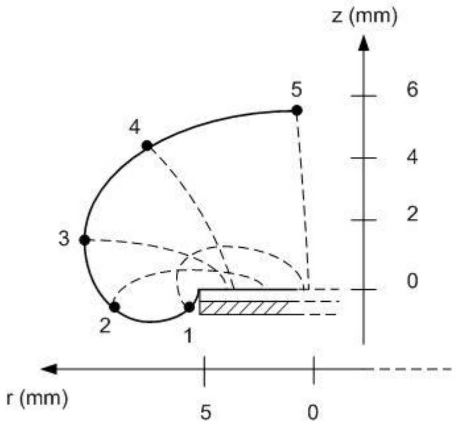

Fig. 1 Schematic plasma-sheath-lens structure with several relevant ion trajectories.

The addition of a magnetic field along the *z* axis results in a twisting of the ion trajectories with a formation of a second passive surface at the centre as shown in Fig. 3 (a) where only a small number of trajectories are illustrated in blue for better visibility [6]. The simulation for more than 10^5 ions is shown in Fig. 3 (b) for a plasma density of 10^{15} m^{-3}, electron temperature of 2 eV, ion mass 40 uam, 1000 Gauss and 10 mm in diameter disk electrode. For a given plasma-sheath-lens configuration and magnetic field strength the diameter of the central passive surface changes with ion mass.

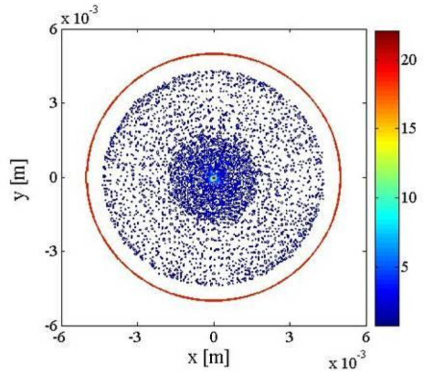

Fig. 2 Ion impact locations without magnetic field.

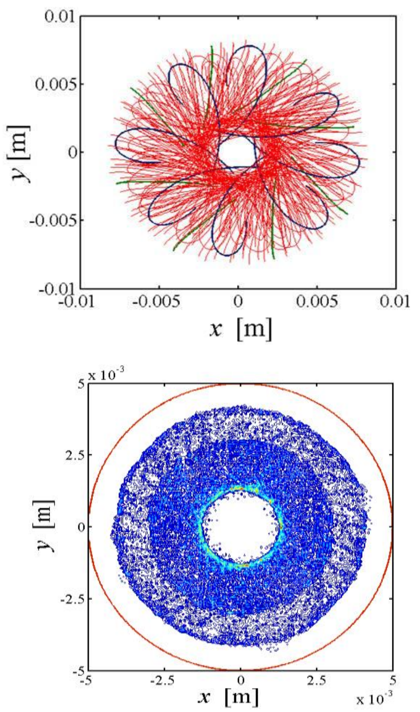

Fig. 3 (a) Ion trajectories twisted by magnetic field; (b) accumulation of more than 10^5 ions on the electrode surface for a magnetized plasma-sheath-lens.

By calculating the ion accumulation in the radial direction for ions of different mass one can detect de location of each mass peak as it is shown in Fig. 4 for a magnetic field of 1000 Gauss. Increasing the disk radius one can improve the mass resolution, increase the distance between the peaks and reduce the magnetic field strength needed to attain the mass separation.

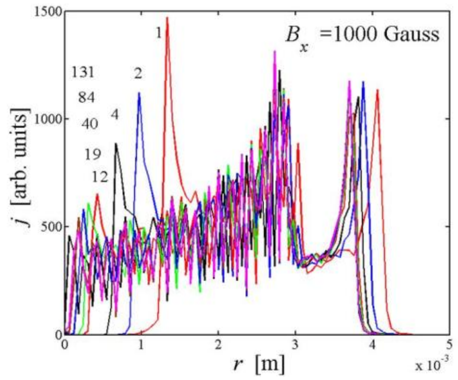

Fig. 4 Radial ion accumulation for ions of different mass indicated in uam with numbers near the peaks for *r*<2 mm.

3. Experimental setup

Experiments are performed in a cylindrical device using three ECR plasma cells at 2.45 GHz developed by Boreal Plasma ® with two magnetic coils able to provide an axial magnetic field up to 600 Gauss. Plasma-sheath-lens structures using disk electrodes with diameters from 1 up to 5 cm one side insulated with ceramic plates are used to detect the mass peaks in gas mixtures of $Ar/SF_6/O_2$. Mass spectrometry, optical emission and probes are available for additional plasma diagnostics. Plasma-sheath-lenses are formed by applying moderate negative voltages (-300 up to -600 V) to electrodes for more than 15 min as to develop the etching profile revealing the mass peaks. Automatic radial scanning using a 0.2x0.2 mm probe driven by a stepper motor to measure an electrical current proportional with local ion flux is also available. Detailed experimental results will be presented during the conference.

4. References

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